Introducing Astronomy in the Pre-K to-12 STEM Curricula, A Resource Guide for Educators

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Introduction

This book covers the topic of Astronomy in the context of STEM Education. Astronomy is the branch of Science that deals with other objects in the Universe. At night, we can see other stars, the moon, sometimes planets, and, if we are lucky, comets. Astronomy dates back far in the history of mankind, starting with observations of the sky, and the development of theories of what it all meant, and how it all worked. The initial assumption was that the Earth was the center of the Universe, and everything traveled around it. But, by observations, some "heavenly bodies" wander about in the sky, and increasingly complex theories were developed to address this. Later, when the Earth was dethroned as the center of the universe, it was understood that other planets and the Earth were in orbit around the Sun. And, the Sun was just another star, like those that could be seen in the night sky.

Early civilizations such as the Babylonians, Chinese, Greeks, Egyptians, the Maya, and many more kept detailed records of the movement of the celestial bodies, in order to develop a theory about what it all meant. With enough data, eclipses and lunar phases could be predicted. The North Star, or the Southern Cross could be used for navigation. Calendars could be produced, and the phases of the moon understood. You knew when to plant crops, and when to harvest them. In Egypt, you knew when the Nile inundation would come. No more guess work. The learned classes or the priesthood understood these phenomena, and were making sense of the world. Well, they still thought the Earth was flat, and the center of the Universe, but their models worked well enough for civilization to advance.

A version of this book was published in Brazilian Portuguese on Amazon-Brazil. Translation was done by Dr. Wesley Gois of the Federal University of ABC, under a program called ASTROEM, a Portuguese acronym for *Astronomy for High School*. Some of the proceeds of the books sales goes to support this program.

Author

Mr. Patrick H. Stakem has been fascinated by the space program since the Vanguard launches in 1957. He received a Bachelors degree in Electrical Engineering from Carnegie-Mellon University, and Masters Degrees in Physics and Compute Science from the Johns Hopkins University. At Carnegie, he worked with a group of undergraduate students to re-assemble, modify, and operate a surplus missile guidance computer, which was later donated to the Smithsonian.

He began his career in Aerospace with Fairchild Industries on the ATS-6 (Applications Technology Satellite-6) program, a communication satellite that developed much of the technology for the TDRSS (Tracking and Data Relay Satellite System). He followed the ATS-6 Program through its operational phase, and worked on other projects at NASA’s Goddard Space Flight Center including the Hubble Space Telescope, the International Ultraviolet Explorer (IUE), the Solar Maximum Mission (SMM), some of the Landsat missions, and Shuttle. He was posted to NASA’s Jet Propulsion Laboratory for Mars-Jupiter-Saturn (MJS-77), which later became the *Voyager* mission, and is still operating and returning data from outside the solar system at this writing. He initiated and lead the international Flight Linux Project for NASA's Earth Sciences Technology Office. He is the recipient of the Shuttle Program Manager's Commendation Award, and has completed 42 NASA Certification courses. He has two NASA Group Achievement Awards, and the Apollo-Soyuz Test Program Award.

Mr. Stakem has been affiliated with the Whiting School of Engineering of the Johns Hopkins University since 2007. Mr. Stakem supported the Summer Engineering Bootcamp Projects at Goddard Space Flight Center for 2 years. He is currently supporting the NASA-Goddard Spaceflight Center Office of Stem Engagement.

What is Astronomy?

Astronomy is the science that focuses on the celestial sky, and the objects visible in it. It is based on physics, mathematics, and chemistry. It is the basis for our understanding of the Universe, and our place in it. Besides, its a chance to get out at night and see the pretty lights.

Astronomy is perhaps the oldest science. It started out as observations by people who were out all night, shepherds mostly. The saw and wondered at the lights in the sky that moved from day to day. It wasn't until priests and shaman began to keep accurate observation records that true astronomy was born. Then theories of what these lights in the sky meant and behaved were evolved. There were at least two kinds of night lights. One class was relatively fixed, and the others wandered, but seemingly according to fixed rules. Observation, record keeping, developing theories of what it all meant.

Obviously, the various gods were in control of these lights. The appearance of particular lights might precede a rain event, tides, and might foretell the optimal planting season or the migration of herds. Structures were built with astronomical alignments (Pyramids and Stonehenge, to mention two). Events repeated at certain intervals, and could be predicted with calendars.

Bone sticks with markings relating to the moon's phases have been found in both Europe and Africa, dated at around 35,000 BC. They are the first known astronomical data entries. A huge calendar was found in a field in Scotland (actually the field and stones are the calendar) dated to 8000BC. There's the recorded observation data being used.

Some models used a solar calendar, some a lunar one. The calendars don't synchronize for 19 solar years and 235 lunations. In Babylon, they compiled star catalogs as far back as 1200 BC. Development of wring and mathematics were driven by a need to record and use the astronomical data. The Babylonians realized that certain events in the sky were repeatable. One tablet lists the risings of Venus over a 21 year span. Astronomical observations drove the development of time-keeping machines, early water clocks. From observed data on clay tablets, the Babylonians created mathematical models that allowed them to accurately predict phenomena. At this time, they used a heliocentric model of the solar system, and went on to influence the Greeks, and most astronomy in Central Asia and Western Europe.

The Egyptians used some of the Babylonian knowledge to align their pyramids with the pole star. Over in the Western Hemisphere, the Mayans observed and recorded astronomical data. Some of their temples are aligned to the rising and setting of Venus. The Muslim astronomers observed other galaxy's than our, terming them little clouds. They also observed in the year 1006, the brightest supernova in recorded history.

In the seventh century, a monk in England published a book of astronomical knowledge, that allowed the prediction of the date of Easter. This was a big deal at the time.

What is STEM?

STEM (Science, Technology, Engineering, Mathematics) is the key to the United States' continued dominance in High Technology. It took a lot of expertise to implement the first cell phone. Now they are turned out like cookies in third world countries.

STEM addresses overall education policy and curriculum sources in schools, at critical grade levels.

Although the teachers are experts in their particular area, and know how to present grade-appropriate material, they may not know how to find and access the advanced resources they need, or where to get help in a particular topic area.

STEM programs are seen as critically important in the education system, world-wide. It is getting to be a complex, interconnected ecosystem. Advances in the subject areas of STEM will take place only by those who know how to exploit this ecosystem for knowledge.

When I was in school well before the Internet and STEM age, I had an encyclopedia. Today, students can access WikiPedia from their smart phones. The focus has changed from knowing facts, which are at your fingertips, on demand, to leveraging facts to innovate. This approach touches all of the academic disciplines, the Humanities, Languages, Art, besides the STEM topics. Perhaps the best skill set to have is good internet search skills. Teachers have had to transition from asking factual questions, to asking questions that derive from applications of online research, and accrued knowledge.

When I was a kid, there was no STEM. My interests in science and engineering led to research and hands on experimentation. Luckily, I survived. I was called on, while in grade school, to lecture and demonstrate some concepts of electricity to a High School class. The first satellite was launched, and I was glued to the black & white TV. I participated in Model Rocketry at the High School Level, and went on to fly Nationally. This was made possible by an extraordinary High School Science teacher. I made quite a few friends, some of whom became Astronauts. I was given a great opportunity when I received a full scholarship to a College of my choice. I went to Carnegie Tech in Pittsburgh (now, Carnegie-Mellon University), and launched a career in Engineering and Aerospace. It is time for me to pay forward.

I think that Astronomy should be a major focal point for STEM, embracing a wide variety of topics at the cutting edge of technology and science. I have a handful of technical degrees, and spent 42 years at the various NASA Centers. I teach Electrical Engineering courses world-wide, and have done specialty Cubesat courses at the undergraduate and graduate level. It is time to apply that expertise earlier in the education process.

My thesis is, a project brings together all of the interesting pieces to provide a focal point for student work. There is a massive body of applicable free support material available from NASA and the Aerospace community. This involves the Education offices at the various NASA Centers, the Visitor's Centers, and the speakers' bureaus. I have taken on the task of making STEM educators aware of this vast treasure-trove of resources. I have experience teaching Cubesat engineering and operations at the advanced undergraduate and graduate level, but I have no experience or credentials at the critical pre-K thru 12 levels. Well, I had my grandson build a a solar system model when he was 3. He did a nice job.

I think STEM is a critical resource for understanding and implementing the future. I think the Astronomy paradigm is a good thing to introduce into STEM. Let's do this. Future generations of STEM-mies will thank us. Possibly from the Mars-base.

Although STEM schools will have in-house expertise in Science (Physics, Chemistry, Biology), and Math (counting numbers through calculus), they are not heavily into Technology and Engineering. That's where you can ask for help – there's a lot of resources and knowledgeable individuals available out there. Reach out to local aerospace companies, or a local NASA Center for help. This book defines a K-12 Program targeted to learning about Astronomy.

What is the Solar System?

Our solar system consists of the Sun, which is our source of power, and a collection of planets, their moons, a large asteroid belt, a collection of comets, and a bunch of miscellaneous rocks. It is a very diverse system, with examples of just about every object imaginable. Mankind has been observing and documenting the solar system for thousands of years. The behavior of the “fixed stars” and the “wanderers” (planets were carefully documented. Many theories of the solar system and the universe in general were postulated. It was obvious that the Earth was the center of the universe, and modeling that universe was extremely difficult. The ancient Greeks were able to untangle the data enough to predict eclipses. It was not until the late middle ages when Copernicus suggested that the Sun might be the center of our solar system, which made the model much simpler, but almost got him thrown out of the Church.

Exploring the Sun

The Sun is the source of our energy, and it keeps the solar system organized. It is about a million times the size of Earth. The Sun is extremely hot due to nuclear reaction. The tiny amount of its energy output that strikes the Earth makes life here possible. All the stars you see at night are other suns that are very far away. Each of these might also have planets. Planets around other stars have been discovered from observation, and by their gravitation effect on their sun.

Each planet in our solar system is in an orbit around the Sun. The time it takes Earth to complete an orbit is what we call a year. Each of the planets have different duration "years." A planet also spins like a ball as it continues in its orbit. The time to complete one revolution is called a "day."

We get all our energy from this huge thermonuclear reactor some 8 light-minutes away. As you get closer to the Sun, its gets hotter, and there is more radiation in terms of energetic particles.

NASA sent a series of probes to closely observe the sun in 1958 and for ten years after. These were the Pioneer 5-9 spacecraft. They didn't get any closer, but provided a different point of view. They got good data on the solar wind and the sun's magnetic field. Pioneer 9 sent back good data for 15 years. The Helios spacecraft in the 1970's were joint U.S.-German missions that got within the orbit of Mercury.

The 1980 Solar Maximum Mission observed the Sun in the spectrum of gamma rays, X-rays, and Ultraviolet. SMM had a failure in its electronics months after launch, but was repaired by a subsequent Shuttle mission. SMM used the NASA Standard

Spacecraft Computer (NSSC-1).The author had flight software onboard SMM, when it reentered the atmosphere and burned in 1989.

A Japanese Mission to study the Sun was Yohkoh, or Sunbeam, in 1991. It imaged solar flares in the x-ray spectrum.

Other US missions included SOHO, the Solar and Heliospheric Observatory, and the Solar Dynamics Observatory. SOHO was located at the Lagrangian point between the Sun and the Earth, while is a null point in the gravity field. It sees the Sun constantly in many selected wavelengths.

The Solar Terrestrial Relations Observatory (Stereo) is a dual spacecraft mission to the Sun, launched in 2006. One is ahead of the Earth in orbit, the other behind. This gives different points of view of solar phenomena.

The Ulysses spacecraft, discussed later in the section on Jupiter, left the plane of the ecliptic (thanks to a Jupiter swing-by) and observed the Sun's high latitudes. One of its discoveries was that large magnetic waves emitted from the Sun scattered galactic cosmic rays.

The Genesis mission was designed to capture and return solar material. It achieved its goal, but was damaged in a crash landing when it returned to Earth in 2004.

Two areas that have never been imaged are the Sun's polar regions. This is because of the very large energy expenditure required to get out of the plane of the ecliptic. This would be a good mission for a Cubesat, or a few Cubesats. The process of achieving an out-of-ecliptic plane and into a path that gets us to the solar poles continues as a research topic.

A proposed mission, the Solar Polar Constellation, would be sent to a high inclination solar orbit.

The latest solar mission, just launched, is the Parker Solar Probe. It is to fly into the lower solar corona. It has a large composite heat shield. It will make seven Venus fly-bys on its way. A highly elliptic orbit around the Sun will be used, to allow the spacecraft to cool off between observations.

How were the planets named? The were named by the early observers after Greek and Roman gods. That practice has been continued as more planets were discovered. The moons of other planets than Earth are generally named after minor deities in the Greece-Roman pantheon. Each planet in our solar system is unique.

Trojan Asteroids are in the same orbit as their primary planet, in front and behind along the orbital path. Earth has 1 moon, and 1 Trojan.

Exploring Mercury

The U. S. Messenger mission to Mercury, the closest planet to the Sun, was launched in 2004. It is currently orbiting the hottest planet. No landing on Mercury has been attempted, although it would be feasible in the *twilight zone* between the extremely hot solar facing side, and the much colder space facing side. Mercury is in tidal lock with the sun, with one side always facing it. It wobbles a bit, creating a twilight zone that is much less extreme. It has no known moons, or Trojans. Being so close to the Sun, it is difficult to observe the planet and its immediate vicinity.

Exploring Venus

The Soviet space program sent a series of probes to Venus. Early efforts were either crushed in the dense atmosphere, or suffered thermal damage. The Venera-7 mission had a goal of surface sample return. It struck the surface harder than planned, but returned temperature data for about 20 minutes. The Venera-8 probe returned data for some 50 minutes. Venera-13 and -14 returned color photos of the surface. Further Soviet and US efforts involved observation from Venus orbit. The Venus environment has proven extremely hostile. It seems our sister world, next towards the Sun from us, is in a environmental runaway condition.

Heavy greenhouse clouds trap the solar energy, and cause massive global warming on a planetary scale. The surface temperature is high enough to melt some metals. This is very hard on computers, and electronics in general. We need to find out what sent wrong on Venus, and try to avoid that on Earth.

Venus' atmosphere is 96% carbon dioxide at a surface pressure of nearly 100 times Earth's, a greenhouse gone wild. It has no moons. Venus is roughly Earth-sized, but something went terribly wrong. It also has clouds of sulfuric acid, that landers have to get through. There is no magnetic field, but there is active volcanism.

Venus Express, an ESA mission, is in Venus Polar orbit. It found a massive double atmospheric vortex (storm) at the south pole. Venus Express operated from 2005-2014. Venus has no moons, but does have Trojans. The Japanese Venus Climate Orbiter "Akatsuki" was launched in 2010, but failed to achieve Venus orbit. It orbited the Sun for 5 years, and was finally got into Venus orbit in 2015.

Venus differs from every other planet in our Solar System in that it rotates in the opposite direction of the other planets. The length of a Venusian year is about 225 Earth days, and its rotation period is 243 days.

Exploring Earth

There are hundreds of Cubesats in orbit around Earth, and some on the International Space Station. In 2018 there will be a Cubesat mission to the moon. Of interest to Cubesat exploration will be the Near Earth Objects (NEO), or Near Earth Asteroids (NEA). Another application is studying the moon's backside, the side that always faces away from Earth. Lunar orbits can be low, since there is essentially no atmosphere. You only have to clear the mountains. The back side of the moon is also an ideal location for a radio telescope, being shaded from the Earth's radio frequency clutter.

Near Earth Objects

Technically, an NEO is a solar system object whose closest approach to the Sun is 1.3 AU, and that comes in close proximity to the Earth There are 14,000 known asteroids in this category, 100 comets, solar orbiting spacecraft, and meteoroids. All these have the potential of striking the Earth. They are closely tracked from the ground, by NASA's Planetary Defense Coordination Office. A joint US/EU project called Spaceguard is tracking NEO's larger than 30 meters. Three NEO's have been visited by spacecraft.

Near-Earth Objects (NEO's), there more than 15,000. Stuff hanging around Earth. Chunks of rock. If these enter the atmosphere, they heat up and burn. Sometimes, enough is left to hit the ground, appearing as a rock. The easiest place to find meteors (as we call asteroids that hit the ground) is Antarctica, where they stand out against the snow and ice. A lot of the Antarctic meteors come from Mars, as one of my old professors proved.

Exploring the Asteroid Belt, dwarf planets, and Centaurs

Asteroids have been imaged by the New Horizons spacecraft, on its way to Pluto, and by the Cassini spacecraft. The Pioneer-10 spacecraft was sent to study the far reaches of the solar system It passed through the Asteroid belt on its way to Jupiter and Saturn.

Although there are fewer than 10 planets, and less than 200 moons, there are millions of asteroids, mostly in the inner solar system. The main asteroid belt is between Mars and Jupiter. Each may be unique, and some may provide needed raw materials for Earth's use. There are three main classifications: carbon-rich, stony, and metallic.

The physical composition of asteroids is varied and poorly understood. Ceres appears to be composed of a rocky core covered by an icy mantle, whereas Vesta may have a nickel-iron core. Hygiea appears to have a uniformly primitive composition of carbonaceous chondrite. Many of the smaller asteroids are piles of rubble held together loosely by gravity. Some have moons themselves, or are co-orbiting binary asteroids. The bottom line is, asteroids are diverse.

It has been suggested that asteroids might be used as a source of materials that may be rare or exhausted on earth (asteroid mining) or materials for constructing space habitats or as refuelling stations for missions. Materials that are heavy and expensive to launch from earth may someday be mined from asteroids and used directly for space manufacturing. Valuable materials such as platinum may be returned to Earth for a profit.

There are only 8 ½ planets, but there are thousands of asteroids, and it seems there may be as many types. This means that exploring the known asteroids is a daunting challenge. On the other hand, the asteroids can be a significant source of raw materials for Earth. A conventional survey and exploration approach would take too long. What is needed instead is a multitude of autonomous and flexible nano-spacecraft. The architectural model is a swarm (social insect model) with distributed intelligence.

The asteroids are not uniformly distributed. In the asteroid belt, the Kirkwood gaps are relatively empty spots. This is caused by orbital resonance of the asteroids with Jupiter. Orbiting irregular shaped bodies is challenging, due to the irregular gravity field. This makes station keeping and attitude control a problem.

Centaurs are icy minor planets between Jupiter and Neptune, and there are 3 known. There may be 44,000 others. Sometimes, they are captured by a planet's gravity, as a moon.

The dwarf planets of our solar system include Ceres. Orcus, Pluto, Salacia, Varuna, Haumea, Quaoar, Makemake, 2007 OR10, Eris, and Sedna. These smaller objects did not make the size cut to be a real planet. These all orbit the Sun. Orcus is a trans-Neptunian object, Salacia, Haumea, Quaoar, Makemake, and Varuna are

Kuiper Belt objects. Eris is the largest of the dwarf planets, having its own moon. Sedna is beyond the Kuiper belt. It's orbital period “year: is 11,400 Earth years. It's in a highly elongated orbit, probably due to Neptune's gravity. Generally, a dwarf planet does not have enough gravity to clear its orbit of other material. Not all dwarf planets have yet been discovered or observed. There may be 10's of thousands.

Exploring Comets

There are some 5,253 known comets. The Deep Impact mission returned images of the surface of comet Borrelly in 2001. That surface was hot (26-70C), dry, and dark. In July of 2005, the same mission sent a probe into Comet Tempel 1. It created a crater, allowing imaging of subsurface material. Water ice was seen. Comet Borrely has a coma, which proved to be vaporized subsurface water ice. Deep Impact went on to complete a flyby of Comet Hartley-2 in 2010.

The 1999 Stardust mission retrieved sample material from the tail of Comet Wild 2 and returned it to Earth in 2006. It released a lander, Philae, which successfully touched down on the comet's surface in 2014.

Pioneer Venus observed Comet Halley while in transit. This was during a period when the comet was not visible from Earth, because of its proximity to the Sun. The Venus probe monitored the loss of water from the comet as it swung around close to the Sun.

Exploring Mars

Mars, and its two tiny moons and seven Trojans has got some infrastructure in place – a communications relay and a weather satellite. There are several Rovers and landers on the surface.

The Viking program was a pair of spacecraft sent to Mars in 1975. Each spacecraft consisted of an orbiter, and a lander. A major target is a Mars sample return mission.

The Mars Pathfinder mission landed on Mars on July 4, 1997. It carried a Rover named Sojourner, which was a 6-wheeled design, with a solar panel for power, but the batteries were not rechargeable. The rest of the lander served as a base station. Communication with the rover was lost in September. It communicated with Earth via the base station using a 9600 baud UHF radio modem. The communication loss leading to end of mission was in the base station communication, while the Rover itself remained functional. The Rover had three cameras, and an x-ray spectrometer.

The MER (Mars Exploration Rovers *Spirit & Opportunity*) are six-wheeled, 400 pound solar-powered robots, launched in 2003 as part of NASA's ongoing Mars Exploration Program. *Opportunity* (MER-B) landed successfully at Meridiani Planum on Mars on January 25, 2004, three weeks after its twin *Spirit* (MER-A) had landed on the other side of the planet. Both used parachutes, a retro-rocket, and a large airbag to land successfully, after transitioning the thin atmosphere of Mars.

The Spirit unit became stuck in 2009, and engineers were unable to free it after 9 months of trying. It was re-tasked as a stationary sensor platform. Contact was lost in 2010.

This is an ongoing mission. It was originally planned for 90 days, but the *Opportunity* Rover is still collecting useful data regarding potential life on our sister planet some 11 years later as of this writing. It has traveled over 35 kilometers on the Martian surface.

The Mars Science Laboratory landed successfully on the Martian surface on August 6, 2012. It had been launched on November 26, 2011. It’s location on Mars is the Gale crater. It is designed to operate for two Martian years (sols). The mission is to determine if Mars could have supported life in the past, which is linked to the presence of liquid water.

The Rover vehicle *Curiosity* weights just about 1 ton (2,000 lbs, 900 kg.) and is 10 feet (3 meters) long. It has autonomous navigation, and is expected to cover about 20 km over the life of the mission. The platform uses six wheels

Communication with Earth uses a direct link, and via a relay spacecraft in Mars orbit. At landing, the one-way communications time to Earth was 13 minutes, 46 seconds. This varies considerably, with the relative positions of Earth and Mars in their orbits around the Sun.

The science payload includes a series of cameras, including one on a robotic arm, a laser-induced laser spectroscopy instrument, an X-ray spectrometer, and x-ray diffraction/fluorescence instrument, a mass spectrometer, a gas chromatograph, and a laser spectrometer. In addition, the Rover hosts a weather station, and radiation detectors. There is cooperation between in-space assets and ground rovers in sighting dust storms by the meteorological satellite in Mars orbit.

Curiosity's exploration of the ancient lake bed, known as Gale Crater resulted in some new discoveries that NASA released on June 7, 2018. It found organic molecules, particularly methane, below the surface. Curiosity has a sampling drill (that, unfortunately, is limited to 5 cm.), a mass spectrometer, and a gas chromatograph. On Earth, most methane is from biological processes. It can be produced by in-organic processes, however. Scientists have also discovered a season pattern in the amount of methane in the atmosphere, in the amount of a factor of three, that may point to sub-surface storage.

The source of the Mars methane has to be resolved. This will be a major goal of NASA's and ESA's next landers. A large underground reservoir of methane could be very useful for return-trip rocket fuel.

NASA's Maven (Mars Atmosphere and Volatile EvolutioN Mission) mission to Mars is an orbiter, to study the Martian atmosphere It was launched in November 2013, and reached Mars in September of 2014. It is still operating as of this writing.

Exploring the Gas Giants

The Gas giants are the planets Jupiter and Saturn. These are the responsibility of the Jet Propulsion Laboratory. These each have extensive ring and moon systems that have been imaged, but not yet explored.

Pioneer 10 was the first mission to Jupiter, followed by Pioneer-11 in 1973, and, as of this writing, there have been 8 total. Jupiter has a very high trapped radiation environment. They are mostly all different, and some are thought to be capable of hosting life, as we know it. The moon Io has volcanic activity, and Europa has water ice on the surface. Europa is considered “one of the most promising extraterrestrial habitable environments in our solar system” according to the most recent Planetary Society's Decadal Survey. A proposed mission, ExCSITE, would provide characterization of the surface properties.

NASA is looking at the Explorer CubeSat for Student Involvement in Travels to Europa (ExCSITE) Mission. This involves multiple Cubesat imagers and impactors.

The Voyager missions were originally terms the “Grand Tour” and were to have visited Mars, Jupiter, and Saturn, with possibly some of the outer planets as well. The mission was called MJS-77. Budget constraints caused the mission to refocus on Jupiter and Saturn alone. The author worked on this mission.

Jupiter

Jupiter has 79 known moons, and perhaps 1 million Trojans of 1 kilometer or larger. The International Astronomical Union has just announced the discovery of 12 previously unknown moons of Jupiter, by an observatory high in the Andes in Chile. Only one has been named so far, Valetudo, a great-granddaughter of Jupiter). and 600,000 known Trojans.

The International Astronomical Union is in charge of name selection for planets, moons, asteroids, comets, and such. Generally, the discoverer submits their suggestion, which is usually confirmed.

These tend to congregate at L4 and L5. The largest has a diameter of several hundred kilometers. The International Astronomical Union just announced as this book was being updated the discovery of 12 previously unknown moons of Jupiter, by an observatory high in the Andes in Chile. Only one has been named so far, Valetudo, a great-granddaughter of Jupiter The one way light time for Jupiter is 33-53 minutes.

Cassini observed the planet from close-up in the year 2000, and studied the atmosphere. Galileo entered Jupiter orbit in 1995, and returned data on the planet and the four Galilean moons until 2003. Three of the moons have thin atmospheres, and may have liquid water. The moon Ganymede has a magnetic field. Galileo was in the right place at the right time to see the comet Showmaker-Levy-9 enter the Jovian atmosphere, and launched an atmospheric probe. The Hubble Space Telescope discovered that the satellite of Jupiter, Ganymede, has a large saltwater ocean, under an ice crust. This is now thought to be the best current hope for finding life on another planet.

The Juno mission to Jupiter has just arrived after 5 years of travel, and was getting settled in to begin its observations. This project was launched in August of 2011, and arrived at Jupiter in July 2016. It was placed in Jupiter elliptical polar orbit for 5 years, and will de-orbit into Jupiter in February 2018. This is to ensure burn-up of the spacecraft to avoid any biological contamination of

Jupiter or its moons. It is scheduled to make 37 orbits. The orbit was chosen to minimize contact with Jupiter's intense trapped radiation belts. It's sensitive electronics are housed in “the Juno Radiation vault,” with 1cm titanium walls. It will have available to it some 420 watts of power, from the solar arrays.

The spacecraft weighed over 1,500 kg. It uses 3 solar panels of 2.7 x 8.9 meters long These are exposed to about 4% of the sunlight at Earth. It left Florida on an Atlas-V vehicle. The perijove, or closest distance to the planet was planned to be 4,200 km. The highest altitude at apojove is 8.1 million kilometers.

It includes infrared and microwave instruments to measure the thermal radiation from Jupiter's atmosphere, being particularly interested in convection currents. It's data will be used to measure the water in Jupiter's atmosphere, and measure atmospheric temperature and composition, and track cloud motions. The mission will also map Jupiter's magnetic and gravity fields. It is expected to probe the magnetosphere in the polar regions and observe the auroras.

Saturn

Saturn and it's 82 known moons has a one-way light time around 1.4 hours. Saturn has been visited by spacecraft four times. The first was a flyby by Pioneer-10 in 1979. This showed the temperature of the planet was 250 degrees K. Voyager-1 visited in 1980. It conducted a close flyby of the moon Titan to study its atmosphere. It is, unfortunately, opaque in visible light. We do know it rains methane. Voyager-2 swung by a year later, and data showed changes in the rings since its sister mission visited the year before. Temperature and pressure profiles of the atmosphere were gathered. Saturn's temperature was measured at 70 degrees above absolute zero at the top of the clouds, and -130 C near the surface. The flybys discovered additional moons, and small gaps in the rings.

Cassini was the fourth spacecraft to study Saturn, which has rings, and is smaller than Jupiter. The rings were confirmed by the Voyager spacecraft in the 1980's. Cassini entered into Saturnian orbit, and is still returning data. The one-way communications time varies from 68-84 minutes. It has also collected data on the Saturnian moons Titan, Enceladus, Mimas, Tethys, Dione, Rhea, Iapetus, and Helene. Things are strange in the Saturnian system. Cassini observed a hurricane in 2006 on the planet's south pole. It appears to be stationary, 5,000 miles (8,300 km) across, 40 miles (67 km) high, with winds of 350 mph (560 kph). The large moon Titan has lakes of a liquid hydrocarbon, with possible seas of methane and ethane. Cassini launched a probe *Huygens* to Titan, and it landed on solid ground below the atmosphere. The Cassini mission was responsible for the discovery of seven new moons of Saturn.

Cassini observed a massive storm on Saturn, the great white spot, that recurs every 30 years. The storm, larger than the red one on Jupiter, exhibited a discharge that spiked the temperature 150 degrees. At the same time, Earth observations showed a large increase in atmospheric ethylene gas. It also discovered large lakes or seas of hydrocarbons near the planet's north pole.

Cassini discovered a possible atmosphere on the moon Enceladus, with ionized water vapor, and ice geysers. Many of the Saturnian moons are in tidal lock with their mother planet. Being so close to its giant neighbor Jupiter affects the Saturnian system.

Cassini cost \$3 billion (\$$10^9$) and couldn't get close enough to Saturn's rings because of the ice particles. One hit could end the mission.

Twenty of the moons were added in 2019, thrusting Saturn ahead of Jupiter for having the most moons. Not all have been named. We're starting to run out of Roman and Greek gods, so the new moons will be I the Norse, Gallic, and Inuit groups. Seventeen of them are in retrograde orbits; they move opposite of Saturn's rotation. The discovery is credited to the Subaru telescope in Hawaii.

Enceladus has definite organic compounds, nitrogen and oxygen based, in plumes.

Exploring the Icy Giants

Uranus and Neptune are the Icy Giants. Their composition differs from that of the ice giants

Uranus

Uranus has 27 known moons, a 13-ring system, and a one-way light time of 2.7 hours from Earth. It has one known Trojan. Uranus was imaged in a flyby by the Voyager-2 spacecraft in 1986. It also captured some images of the Uranian moon Umbriel. But, Uranus and Neptune are two of the great remaining unknowns in the solar system, since neither have been explored in detail, by a dedicated mission. There is a desire to put an explorer spacecraft in orbit, and use that as a platform to launch probes into the atmosphere.
Uranus and Neptune are sometimes referred to as ice giants, since their atmospheres are known to contain water, ammonia, and methane ice. Uranus has a magnetic field. Interestingly, Uranus' spin axis is tilted into the plane of its orbit around the Sun. Seasonal changes and weather have been observed. The Voyager-2 mission imaged Uranus on its way from Jupiter, and out of the solar system. Atmospheric wind speeds are know to approach 900 kilometers per hour. It's orbit period is 84 Earth years. It receives about 1/400th of the light that the Earth does from the Sun, so solar power is probably not a viable choice.

Because of the strange orientation of the planet's rotation axis, during the solstice, one side of the planet faces the Sun continuously, and the other faces deep space. Each pole gets 42 years of direct (though weak) sunlight, and 42 years of darkness. In spite of this, the equator is the hottest region. At this writing, the planet is in its autumnal equinox.

Uranus has a strange predominately water-ammonia ocean, which is electrically conductive. A major targeted mission is the Uranus orbiter and Probe. Mission analysis comes up with a 12-13 year cruise from Earth to Uranus.

Neptune

Neptune has 14 known moons, and 18 known Trojans. It's one-way light time is around 4.3 hours. Neptune has also been visited by Voyager-2 in 1989. It discovered six new moons. That is the extent of close-up observations of the planet. Neptune has rings, like Jupiter and Saturn, and a great dark spot. It's moon Triton has geysers and polar caps. Triton has an interesting retrograde orbit – it goes in a different direction than the other moons. Triton's surface is mostly frozen nitrogen, and is geologically active. It is speculated that Triton has a subterranean ocean. The moon Ptoteus is an ellipsoid, not a sphere.

Exploring Pluto, and beyond

Pluto was downgraded from a planet to a Kuiper Belt object. The *New Horizons* mission to Pluto and the Kuiper Belt began in January of 2006, and reached the vicinity of Pluto in July 2015. It conducted a 6-month survey of Pluto, and went out farther into the Kuiper belt, on an 3 year extended mission, which is ongoing at this writing. The spacecraft was developed for NASA by the Johns Hopkins University Applied Physics Lab in Laurel, MD.

In March of 2007, the mission computer experienced an uncorrectable memory error and rebooted itself, causing the spacecraft to go into safe mode. The craft fully recovered within two days, with some data loss on Jupiter's magnetotail. The one-way light time back to Earth was 4.6 hours.

In 2015, the Pluto flyby occurred, and data began to flow back to Earth. It took more than a year for all the imaging data to be transmitted, due to distances and transmit power involved.

Pluto had one known moon, Charon, before the New Horizons Team members, using Hubble Space Telescope data, discovered four more, Nix, Hydra, Styx, and Kerebos.

Kuiper Belt Objects

The Kuiper Belt extends from the orbit of Neptune out approximately 50 AU. There are three known dwarf planets, the formal Planet Pluto and two others. Over 100,000 units are speculated to exist. Neptune has a major gravitational influence over the Kuiper belt objects. Not much is known about the belt and its objects, since astronomers have had to rely on ground based observation. The New Horizons mission is proceeding out through the Kuiper belt, and will tell us what it sees.

Beyond the Kuiper belt is the Scattered disc, extending beyond 100 AU. This is a sparsely populated region of the solar system. This is no knowledge of how many scattered disk objects (SDO's) exist. The closest is at around 30 AU. The belt extends above and below the ecliptic plane, in a torus configuration.

Beyond this is the Oort Cloud, extending out 5,000 – 100,000 AU. There is a disk-shaped inner cloud, and a spherical outer cloud. And you thought space was empty.

I didn't total all this up, but it doesn't seem like this is a small task. We need to get a lot of spacecraft working on it. U.S. Spacecraft have visited all of the planets in the Solar System (including the demoted Pluto), and many of the other objects as well

Comets

A comet is an icy solar system body usually in a large, elliptical orbit. There are 5,253 known. As a comet approaches the Sun, it heats up and boils off material that forms a long tail called a coma, it's most spectacular aspect.

From somewhere else

Not everything in our solar system is from around here. Generally, our solar system bodies orbit the Sun in a disk called the ecliptic plane. Comets that are not necessarily in orbit around our Sun can take a path that are highly inclined to that plane. As this book was being written, the first asteroid at a very high angle with respect to the ecliptic was observed. That means it did not originate in our solar system, but came from some where else in our galaxy, or beyond. There is no particular name for this class of objects, but the title “Exeroid” has been suggested. This will have to be cleared with the International Astronomical Union. The object was observed by a telescope on the Hawaiian mountain of Hakeakala. It is the first time an interstellar object has been observed. It was named Oumuamua, in Hawaiian, “messenger from a far, arriving first.” It came from the direction of the constellation Lyra. It was first spotted on October 19, 2017.

The Stars, our Galaxy and others, the Universe and all that.

The stars

The stars we see from Earth seem to be arranged in patterns, forming what the ancients saw as constellations. In reality, from out point of view, there are patterns, but those stars are at widely ranging distances from Earth. We can determine distances from a physics phenomena called the red shift. First, we determine if the light from the star is shifted to a higher or lower frequency. How do we know what it started out to be? The spectral bands of common elements is observed. All of the elements' spectral lines will be shifted the same amount. Comparing that to a “normal” spectrum will give the shift. If there is a red shift, there is an increase in wavelength, and the observed object is moving away from us. Similarly, a blue shift is a decrease in wavelength, and the object is moving toward us. The amount of the shift gives the velocity. The amount of shift is affected by relativistic effects at velocities approaching the speed of light.

A special class of pulsating stars is called the Cepheids. They are noticeable by changes in brightness, and usually exhibits stable behavior. There is a direct correlation between the luminosity of the star, and its period. Knowing that, scientists can use those stars as measures of distance. The first was discovered in 1784, but the behavior was not understood until around 1908. The pulsations can be on the order of days or months.

A nova is a transient astronomical event involving a bright new star that fades over time.

The Main Sequence of Stars is a chart of color versus brightness. The chart is referred to as the Hertzsprung-Russell diagram. Most known stars fit within the diagram.

A binary star is a star system, with the two stars orbiting a common point. If there's more than two, it is just referred to as a star system.

A Neutron star is the collapsed core of a very large star. The original star had to have a mass of around 10-30 times greater than our Sun. They are small and dense, with a radius of around 10 kilometers, and weighing about 2 solar masses. They result from a supernova explosion of the original star, followed by gravitational collapse which compresses what's left to the density of atomic nuclei, with no spaces. They have large magnetic fields, and rotate very quickly.

A supernova is an end-of-life explosion of a star. Observed from Earth, there is a brilliant new bright light in the sky, that gradually fades. There have been three supernova events observed in the

Milky Way in the last thousand years.

A dwarf star is smaller than our Sun. They come in white, black, brown, red, yellow, orange and possibly blue. These stars are not dense enough to collapse into a neutron star at end-of-life. A black dwarf no longer emits visible light. A blue dwarf has not been observed, but is postulated to exist.

A black hole is an object that has a gravitational field that is too strong for even light to escape. It is postulated to warp spacetime itself. The boundary around the black hole is known as the event horizon. Black holes may be the result of the collapse of a very massive star. These are usually found in the galactic core. They create gravitational waves, which have just recently been observed. The concept of a Black Hole, which is essentially a point mass, was first suggested in 1784. There is a supermassive black hole at the center of the Milky Way.

A Galaxy, like our own Milky Way, is a collection of stars, gas, dust, and dark matter, gravitationaly bound together. The objects orbit the galaxy's center of mass, and can be of an elliptical, spiral, or irregular shape. Between the stars and other objects in a galaxy is a gas, with a density around 1 atom per cubic meter. There are estimated to be around 10^{11} - 10^{12} galaxy's in our observable universe, each having 10^{8} to 10^{14} stars.

The Magellanic Clouds are made up of two dwarf galaxies in the southern sky, The cloud orbits our Milky Way Galaxy. These phenomena were noted by the Khoisan People of Southern Africa. The early Polynesian peoples used them as navigation aids. There is a large cloud, and a small cloud.

A Nebula is an interstellar cloud of dust and gases, spanning millions of light years. The most prominent one, from our viewpoint is the Orion Nebula, visible with the naked eye. Stars are formed in nebula, from the concentration of matter. Ptolemy the Greek observed a nebula around the year 150. The Andromeda Nebula was observed by a Muslim astronomer in the 10th century. He named it, “Little Cloud.” Later, Edwin Hubble identified it as a different galaxy than ours.

A Pulsar is a magnetized, rotating neutron star. Like a lighthouse, it emits a beam of electromagnetic radiation in one direction. Observed from Earth, it looks like it is pulsing. The stars have very regular rotation rates, and thus the pulses appear at very precise intervals. They can be used to time other events. They were discovered in 1967.

Star clusters are groups of stars. A Global cluster has thousands of old stars, an open cluster is more loosely configured, and consists of younger stars. A cluster tend to be spherical, and the constituent stars tend to be the same age. The Pleiades are an example of an open star cluster.

It is a strange Universe out there.....

HST

The biggest example of this is the Hubble Space Telescope, a NASA-Goddard Project, managed by the Johns Hopkins University, at the Baltimore Campus. The science data center and archive is the Space Telescope Science Institute. The mission was launched in 1990, repaired in space by several Shuttle Missions, and is returning good data as of this writing. One of Hubble's notable achievements was the determination of the rate of expansion of the Universe.

The Hubble may last another 15-20 years. It is not currently feasible to mount another repair mission. A robotic servicing mission may be attempted.

The main mirror is almost 8 feet in diameter. The telescope operates in the visible spectrum, as well as near ultraviolet and near infrared, which don't make it through the atmosphere. Precursor missions include the Orbiting Solar Observatory, and the Orbiting Astronautical Observatory, both from NASA's Goddard Space Flight Center. Hubble uses a Cassegrainian reflector design, from Marshall Space Flight Center, and built by Perkin-Elmer.

They subcontracted the mirror to Kodak, using Corning glass. This was coated with aluminum.

After only a few weeks in orbit, it became obvious that the mirror was flawed. Corrective optics were designed, and several Shuttle flight got the orbiting facility back to its desired accuracy. At the same time, updated equipment was installed, and a failed module was replaced.

Like most Earth-based observatories, scientists can apply to use the HST for observations. Competition is fierce for observing time. In the period 1990-1997, the director of the StScI allowed amateur astronomers access to the facility for free. Thirteen amateurs were involved.

The contributions of the HST mission to our knowledge of the Universe are impressive. Hubble observations now put the estimated age of the Universe at around 14 x 10^9 years.

JWST

The James Webb Space Telescope is the next big ambitious Telescope-in-Space Project. It has been in work for some 25 years, and is scheduled to be launched in 2019, as of this writing. It will be launched to a location behind the moon, to shield it from Earth interference. It is an infrared telescope, so a large heat shield is needed to avoid sunlight interference. It operates in the long wavelength (orange to red) visible spectrum, and into the mid-infrared. It is a follow-on, but not a replacement for the Hubble. It is a joint US-ESA-CSA project.

Partially to avoid the prior problem with the main mirror, the JWST has a large set of small, adjustable mirrors, individually controllable. They are gold-coated beryllium.

The project was a concept in the mid-1990's and construction was completed in November of 2016. It is in testing at the moment. It was originally called the Next Generation Space Telescope (NGST), but was named after James Webb, the second NASA administrator.

Where Hubble has a 2.4 meter single-piece mirror, JWST has 18 segments for a combined size of 6.5 meters. These segments are folded for launch, and deploy in orbit. It has curved secondary and tertiary mirrors. Instruments include a near infrared camera, a near infrared spectrograph, a mid-infrared instrument, and a near infrared imager with a slit-less spectrograph. The telescope is expected to see extra-solar planets (planets around other stars). The telescope masses 6.5 tons. It will be launched on an Ariane vehicle

It is not designed to be serviceable. It has a projected lifetime of 5 years, with a goal of twice that. Originally estimated to cost a half-billion dollars in 1997, the current cost looks in the vicinity of 8.8 billion dollars.

It will be operated from the same facility that Hubble is, the Space Telescope Science Institute, on the campus of the Johns Hopkins University in Baltimore, MD.

As of this writing, plans are for launch in 2019..

Suggested Projects

This section presents a list of suggested projects, as a starting point to get students engaged with astronomy.

Step 1 – get a telescope. Maybe build a telescope. Find a good location for it, away from light pollution. You might have to do field trips at night to allow clear viewing.

I was amazed at the Southern Sky viewed from Brazil. At the south end of the Sahara Desert, the Northern Sky presented an awesome view.

Locate a local Planetarium, and do a field trip. Some of the NASA Centers, like Goddard in Greenbelt, have one. There's a good one in Hawaii.

Choose a place to visit in our solar system. Do some research on Google, Wikipedia, and the NASA sites. Write a logbook on your travels to your suggested destination, and what you observed.

Not all astronomy is done in the visible light realm. In Greenbank, West Virginia, the National Radio Astronomy Observatory is located. If you're close enough, it's worth a visit. A very large radio telescope is also located in Puerto Rico, the Arecibo Observatory, operated by the National Science Foundation. It has a span of 305 meters, and is built into a natural depression like a sinkhole. It is no longer the largest such telescope, with the completion in 2016 of the Five Meter Aperture Spherical Telescope in China.

NASA's Wallops Flight Facility, on the Eastern Shore of Virginia, hosts an "International Observe the Moon" night event periodically. They also have an Astronomy Night at their Visitor's Center. Chat with local Universities, who usually have astronomy resources,

Student Exercises

Here are some suggestions to get students interested in Astronomy.

- Have the students construct a model of the solar system, assigning different planets to different groups. Make the Sun a light bulb. Include Earth's moon. Demonstrate how the distance between different planets can vary.
- Have a student team research and document a trip to a planet in a distant star system.
- Have a student team research and construct a sundial.
- Schedule a field trip to a nearby planetarium.
- Have the students construct a reflecting telescope. Buy the mirror and the eyepiece. Amazon has them.
- Schedule a night viewing exercise, with specific targets to see. Sketch the lunar phases, over a period of a month.
- If feasible, visit one of the NASA Centers and the Smithsonian Air and Space facility (see the authors book on this topic).

- If you are close to a NASA Center, contact the Education office there. These facilities have a lot of material to provide, and Speaker's bureau's where a guest lecturer will visit your school.
- The Space Telescope Science Institute, on the JHU Campus in Baltimore, has a very active public outreach program, with awesome educational materials online. The contact information is given in the Resources section below.
- Try to observe a lunar and a solar eclipse, schedule permitting.

And in Conclusion...

The National STEM program is key to the United States' and the World's dominance and application of advanced technologies. I can't say for a fact that every nation has STEM programs, but a lot do. Along the way, students have learned a lot about the Universe in general. Most importantly, we have gotten them interested and engaged. Even if they never do another Astronomy project in their life, they will understand the process, its applications, and its limitations. Some of them will go on to explore Mars, or find solutions to problems we are not yet aware of. Maybe these will be your students.

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Resources

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- https://www.nasa.gov/connect/apps.html
- https://www.nasa.gov/mission_pages/
- GSFC-Education@mail.nasa.gov
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- Space Telescope Science Institute public outreach, http://outreachoffice.stsci.edu/
- https://spacemath.gsfc.nasa.gov/
- wikipedia, various.

Glossary of terms

Apojove – the point furthest away from Jupiter by a body that orbits it.

ASIN – Amazon Standard Inventory Number.

Asteroid – a chunk of rock; a minor planet.

Asteroid belt – a disc in the solar system between Mars and Jupiter, occupied by chunks of rock in various sizes.

AU – astronomical unit, mean distance from the Earth to the Sun, 93,000,000 miles.

Binary star – two stars in orbit around a common point.

Black hole – a collapsed star, compressed so dense that not even light can escape; a singularity.

Blue Moon – intercalary moon, 13 full moons in a year instead of 12.

Blue Shift – an apparent shift of electromagnetic radiation toward decreasing wavelength

Centaur – a minor planet in an unstable orbit, behaving like an asteroid or comet.

Cepheid – a variable star.

Cluster – groups of stars.

CME – Coronal Mass Ejection – burst of plasma and magnetic fields from a star's corona.

Coma – Comet's tail

Comet – a solar system object consisting of ice, dust, and gas, in highly eccentric orbit.

Constellation – patterns we see in collections of stars.

CSA – Canadian Space Agency

Dwarf planet – planet below a certain size.

Dwarf star – small star, much smaller than our Sun. Comes in white, red, blue and black variations.

Ecliptic – the apparent path that the Sun seems to follow, the same as the Earth's orbit.

Equinox – 2 days per year when there are equal periods of daylight and darkness.

ESA – European Space Agency.

EU – European Union.
Exeroid – proposed name for a asteroid-like body from out of outer solar system.
Exoplanet – planet in another solar system.
Galaxy – a loosely coupled collection of 10^8 to 10^{14} stars.
Gas giant – a large planet consisting mostly of hydrogen and helium. Jupiter and Saturn.
Heliosphere – a volume of space dominated by the Sun. In our case, out beyond Pluto.
IAU – International Astronomical Union.
Heliocentric – sun-centered.
HST – Hubble Space Telescope.
IAU – International Astronomical Union.
Ice giant – large planet consisting of ices of various substances – Uranus and Neptune.
ISBN – International Standard Book Number.
JHU – Johns Hopkins University.
Jovian – pertaining to Jupiter.
JPL – NASA's Jet Propulsion Lab, Pasadena, California.
KBO – Kuiper Belt objects.
Kuiper Belt – disc in the solar system from Neptune out about 50AU.
LGM – little green men.
Light year – the distance light travels in one year. $9.5 \text{ x}10^{12}$ kilometers.
Lunation – synodic month; average period of a moon's rotation.
Magellanic clouds – two dwarf galaxies in the southern sky.
Magnetotail – a long stream of charged particles, held by magnetic forces.
Mbps – 10^6 bits per second.
Mbytes – mega (10^6) bytes.
Milky Way – our Sun is in this Galaxy.
Moon – smaller astronomical body in orbit of a planet.
NASA – National Aeronautics and Space Administration.
Nebula – interstellar cloud of dust and gasses.
NEO – near Earth object.
Neutron star – collapsed core of a large star. Very dense.

NGST – Next Generation Space Telescope – renamed after James Webb.

Nova – transient astronomical event involving a bright new star that fades over time.

NSF – (U.S.) National Science Foundation.

Orbit – the path of one body around another, that are linked by gravity

Perijove – the point in an orbit closest to Jupiter by an object that orbits it.

Parsec – parallel second of arc, unit of length, about 3.26 light years.

Planet – a body orbiting a star.

Pleides – an open star cluster.

Pulsar – highly magentized rotating neutron star of white dwarf.

Red Shift – an apparent shift of electromagnetic radiation toward an increasing wavelength due to the doppler effect.

Ring system – a disk of solid material around a planet.

SD – scattered disk, a distant ring of smaller solar system objects, beyond Neptune

SDO – scattered disk object

SMM – Solar Maximum Mission.

Solar flare – a sudden rapid emission of electrons, ions, and atoms from a star.

Solar System – A star and its associated planets and such.

Solar wind – stream of charged particles emitted from a star's upper atmosphere.

Solstice – day of the shortest or longest period of daylight.

StScI – Space Telescope Science Institute (JHU)

Supernova – a massive explosion of a star, at its end of life.

Tidal lock – where the same side of a object always faces the primary it is orbiting.

TNO – trans-Neptunian objects.

Trojan – minor planet that shares an orbit with one of the larger planets.

VIM – Voyager Interstellar Mission.

WFIrST - Wide Field Infrared Survey Telescope.

White dwarf – very dense remnant of a stellar core.

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